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ON THE RADIAL VELOCITIES OF NEBULAE

By W. W. Campbell

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Presented to the Academy, October 31, 1914

The discovery, early in 1910, that the velocities of the stars are functions of their spectral types—the stellar velocities increase rapidly, on the average, as we pass from the blue stars through the yellow stars and on to the red stars—and the prevailing opinion that the stars have been evolved from nebulae, gave special interest to the search for possible relationships existing between nebular and stellar velocities. The nebular velocities then available were the velocities of approach and recession (radial velocities) of 13 planetary nebulae and of the Orion nebula, as observed by Keeler in 1890–1891 with a visual spectroscope attached to the 36-inch refracting telescope. The average radial velocity of the 14 nebulae, as observed by Keeler, was 25 km. per second; or omitting the Orion nebula, whose velocity is close to zero, 26½ km. per second for the 13 planetaries on his list. The average radial velocity of the helium stars, very generally supposed to be the stars most recently formed from nebulae, was found to be only 6 km. per second. The average nebular velocity was four times as great. Were Keeler's results, only 14 in number, too few to furnish a safe statistical basis of comparison? The basis was at least too small to support a superstructure of any pretensions to reliability. A knowledge of a greatly increased number of nebular velocities was strongly demanded.

During the past three years, at the Lick Observatory and at the associated D. O. Mills Observatory, Santiago, Chile, more than 200 measures of nebular radial velocities have been secured by spectrographic methods. These relate to 61 nebulae, but as 7 of these objects have been observed only once each, this note is limited to the velocities of 54 nebulae.

The distribution of the velocities, as to magnitude, tabulated below is remarkable. No distinction between velocities of approach and velocities of recession is made in this table.

Velocities, km./sec.	0–10	10–20	20–40	40–60	60–80	80–up
Number of nebulae	11	6	17	11	2	7
Average velocity	5	16	28	50	77	132

Total number of nebulae 54. Grand average velocity 42 km./sec.

It is now well known that the radial velocities of four-fifths of the so-called helium stars are under 10 km. per second, and that the average for all helium stars is about 6 km. per second. Of the observed nebular velocities only one-fifth are under 10 km. per second, and the average for the 54 observed objects is 42 km. per second, or 7 times that of the helium stars. The velocities of the helium stars follow pretty closely the so-called 'probability curve'—a great number of small velocities and very few large velocities. The nebular velocities do not follow the probability curve at all.

If we omit velocities greater than 60 km. per second, as abnormal, we find the *average radial velocity of 45 nebulae to be 26.4 km. per second,* which is still 4 times the average for all the helium stars.

Omitting 12 extended and ring nebulae we find that *the average radial velocity of 42 planetary nebulae is 46.1 km. per second.*

The velocities of the extended and ring nebulae seem to be habitually low, but the number of these included in the program thus far is too small to serve as a safe basis for drawing conclusions. The nebulae N. G. C. 6644 (α = 18h 26m, $\delta = -25.2°$) and N. G. C.$_2$ 4732 (α = 18h 28m, $\delta = -22.7°$), which are less than 3° apart, have velocities 202 km. per second recession, and 141 km. per second approach, respectively—a relative radial motion of 343 km. per second.

In general, assuming that the motions of celestial bodies are substantially at random in direction and speed, the average radial velocity of a considerable number of objects is exactly one-half of the average space velocity of the objects. We shall probably not be far wrong in assuming that the average radial velocity of 42 km. per second for the 54 nebulae means that the average space velocity of the same objects is approximately 84 km. per second.

All of the above results have been freed from the effects of the sun's motion as determined from spectrographic observations of the stars.

The algebraic mean of the 54 observed velocities, after correcting for the effects of the sun's motion, is -2 km. per second. There is thus no indication of a systematic tendency of the planetary nebulae for motions of approach or of recession.

These observations refer exclusively to nebulae whose spectra are composed chiefly of bright lines, and there are no spiral nebulae on this list.

With reference to stellar motions, the planetary nebulae are rapid travellers. Does this fact throw any light upon their origin or their possible relation to stars? A few of the stars are known to be travelling rapidly. These rapid travellers are found mostly amongst the yellow and red stars, which are usually held to be furthest removed from the nebular condition. Perhaps the best explanation of the so-called novae, or new stars—stars which suddenly flash up where previously no stars, or at the best, very faint stars, were known to exist—is that they are due to the rushing of dark or relatively faint stars through invisible nebulae or resisting media. The resulting collisions, in effect a bombardment of the stellar surfaces, seem to generate sufficient heat to convert the surface strata of the stars into incandescent gases and vapors. Spectrographic observations have shown for all recent novae that in the course of a few weeks or months the spectra of the novae are converted into the nebular type. Later the nebular spectra disappear and a certain type of stellar spectrum takes their place. These changes occur rapidly, perhaps because the bombardment effects have been but skin deep.

That planetary nebulae may have resulted in some such way from the collisions of stars and the resisting media seems quite possible. Exactly those stars which are travelling with very high speeds would have the greatest chance to encounter resisting media: and further, the disturbances would be deeper and more permanent the higher the speed of collision. Conversely, if this speculation has a basis in fact, that is, if the planetary nebulae have been formed in this manner, the prevailing high velocities would find a natural explanation.

In securing the difficult long-exposure observations upon which this note is based, I have been greatly assisted by several members of our staff, especially by J. H. Moore, E. S. Haynes, and P. W. Merrill.

PRELIMINARY NOTE ON NEBULAR PROPER MOTIONS

By H. D. Curtis

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The great number of nebulae in the sky, their well-known grouping in regions distant from the Milky Way, the spiral structure so frequently occurring, and the question as to the place of these bodies in the evolution of the sidereal universe, all present a series of problems as yet only partially solved.

A knowledge of the proper motions or of any rotational movements which these bodies may have would be of very great value in investigations as to the size and distance of the nebulae, and therefore as to their place in the structure of the visible universe. Owing to the hazy and diffuse character of the great majority of nebulae when observed visually, the visual observations of the past, just as they have proved nearly valueless in giving an adequate conception of the form and structure